RF Exposure Policies Updates

Laboratory Division

Office of Engineering and Technology

Alfonso Tarditi, Tim Harrington

Note: The views expressed in this presentation are those of the authors and may not necessarily represent the views of the Federal Communications Commission.

Acknowledgement

We would like to gratefully acknowledge insightful contributions from conversations with Dr. Quirino Balzano (U. of Maryland).

Topics

- RF Exposure Equipment Authorization Policies
- Re-Iterating KDB 447498 Transition Policy
- KDB 447498 Revision
- Unintentional Radiator Sources (URS)
- URS Workflow for RFX Compliance
  - *Deep Dive 1* - URS Coupled in the Near-Field
  - *Deep Dive 2* - URS Power Estimates from Near-Field Data
- Forthcoming RF Exposure Policies
- Q&A

RF Exposure Equipment Authorization Policies

This presentation provides an outline of forthcoming policies not yet in effect

- This presentation does not supersede presently established equipment authorization guidance
- New provisions or changes to old guidance referred to in this presentation will be formalized in the new edition of KDB 447498-v07, and will be officially effective only upon issuance of the KDB Publication document
- Ample ahead notice will be given to industry and TCBs, to enable a smooth transition
- RF exposure guidance provided at past workshops that is still in effect is being incorporated in the related KDB Publications: applicable guidelines may be used for equipment authorization as long as no newer policy was issued

Re-Iterating KDB 447498 Transition Policy

- No changes for the KDB 447498 transition -

KDB 447498 "Main page"

- Until further notice, either 447498 D04, or the previous KDB Pub. 447498 D01 v06 may continue to be used:
  - No mix of old and new procedures within application filings
  - A transition period date will be announced (with ample advance notice)
- For devices using 447498 v06 and not subject to PAG:
  - Form-731s and associated grants must be submitted to FCC by a TCB on or before the end of the transition period
- For devices using 447498 v06 and subject to PAG:
  - TCB must submit PAG KDB inquiry and fully-populated Form-731 application on or before the end of the transition period

KDB 447498 Revision

- All past comments on 447498-draft reviewed and accounted for (thanks!)
- 447498-v07 Document release postponed to after the workshop due to the following tasks still in progress
  - Tweaks for the Unintentional Radiator Sources (URS) policy
  - Coordination with *Module* publication 996369
  - Coordination with other RF-exposure-related publications
  - Coordination with KDB 680106 (Wireless Power Transfer)
  - Establishment of a “relaxed” transition period to avoid pressure on TCBs and labs

Unintentional Radiator Sources (URS) (I)

Proposed RF eXposure Updates for URS

- Leveraging Part 15 B test data: it will be shown how, in the large majority of cases, EMC test data can be used for addressing RFX compliance
- URS exempted from authorization per §§ 15.23, 15.103, and 15.113 to be considered under a separate provision
- Special cases have been vetted
  - Analysis of possible inaccuracy issues related to Part 15 Testing
  - Identified possible infrequent/unusual non-compliance scenarios
- Updated integration of URS in the general workflow of establishing RFX compliance for Equipment Authorization

Unintentional Radiator Sources (URS) (II)

Leveraging Part 15B Data

- Compliance with Part 15B imposes limits to the maximum radiated emissions that correspond to negligible levels of the URS radiated power
- Worst-case scenario estimate: §15.109 prescribes a max. electric field E=500 $\mu V/m$ at 3 meters
- In the far-field, an isotropic radiator will be then limited to a power of P=75 nW, *i.e.*, less than 4 orders of magnitude smaller than the 1-mW RFX test exemption

$$P = 4\pi r^2 \frac{E^2}{Z_0} = 4\pi r^2 \frac{E^2}{120\pi} = r^2 \frac{E^2}{30} \Rightarrow P = 3.^2 \frac{\left(500.\cdot 10^{-6}\right)^2}{30.} \approx 7.5\ 10^{-8}\ W$$

Unintentional Radiator Sources (URS) (III)

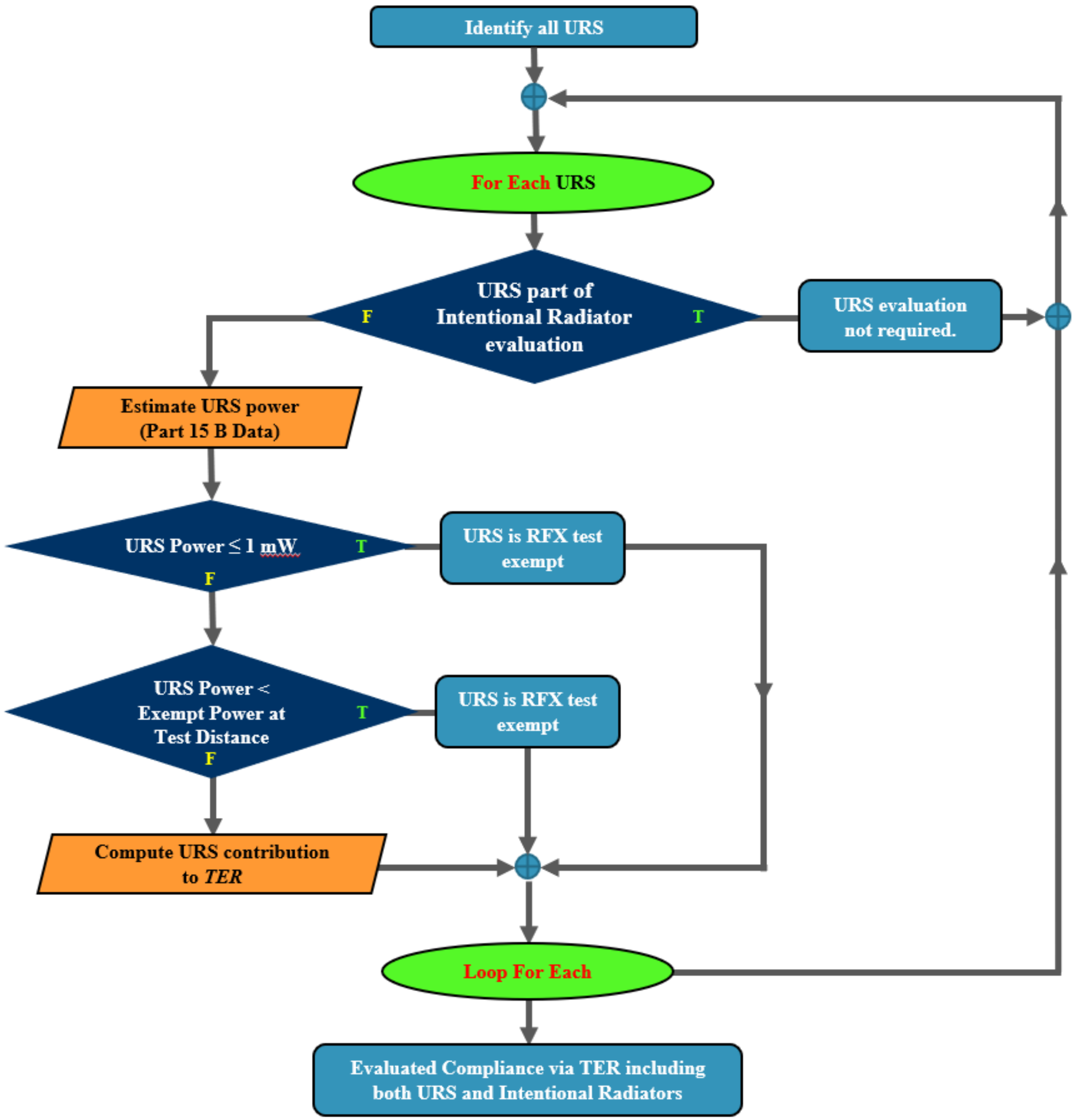
Part 15B Test Data Applicability

- If the “15B test” data are collected in the absence of nearby field-perturbing objects near the source (free-space type of emissions), then per conservation of energy the total radiated power measured in the far field corresponds to the RF source power.
- Two issues that could challenge the use of the power estimate via 15B test data have been analyzed
  - The URS is operated while coupled in the near-field with another object
  - The Part 15B test position is not in the far-field
- The analysis performed so far shows that both these cases have a negligible impact on the power estimate, except for a few special scenarios

URS Workflow for RFX Compliance

Draft Process Flowchart

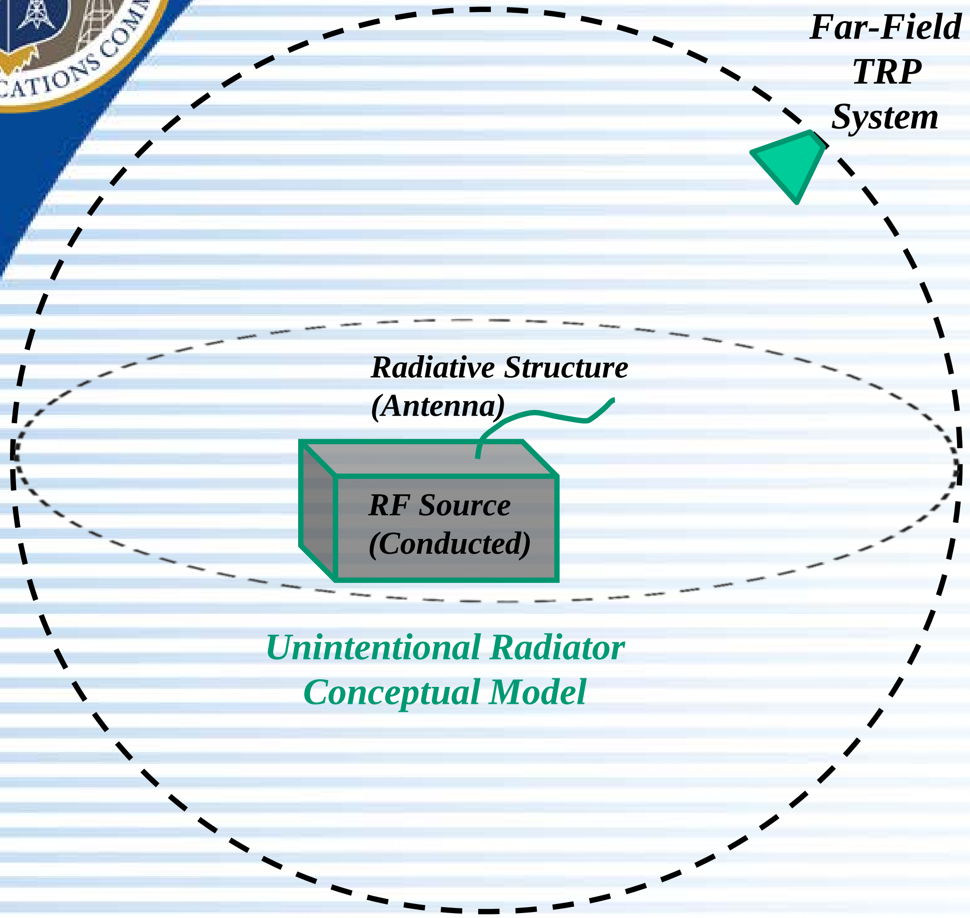
- Integration of URS in the general RFX compliance evaluation process
- Power estimate relies mostly on Part 15B data analysis (additional provisions will address 15B-exempt devices)
- In most cases URS will not need to be RF Exposure evaluation.

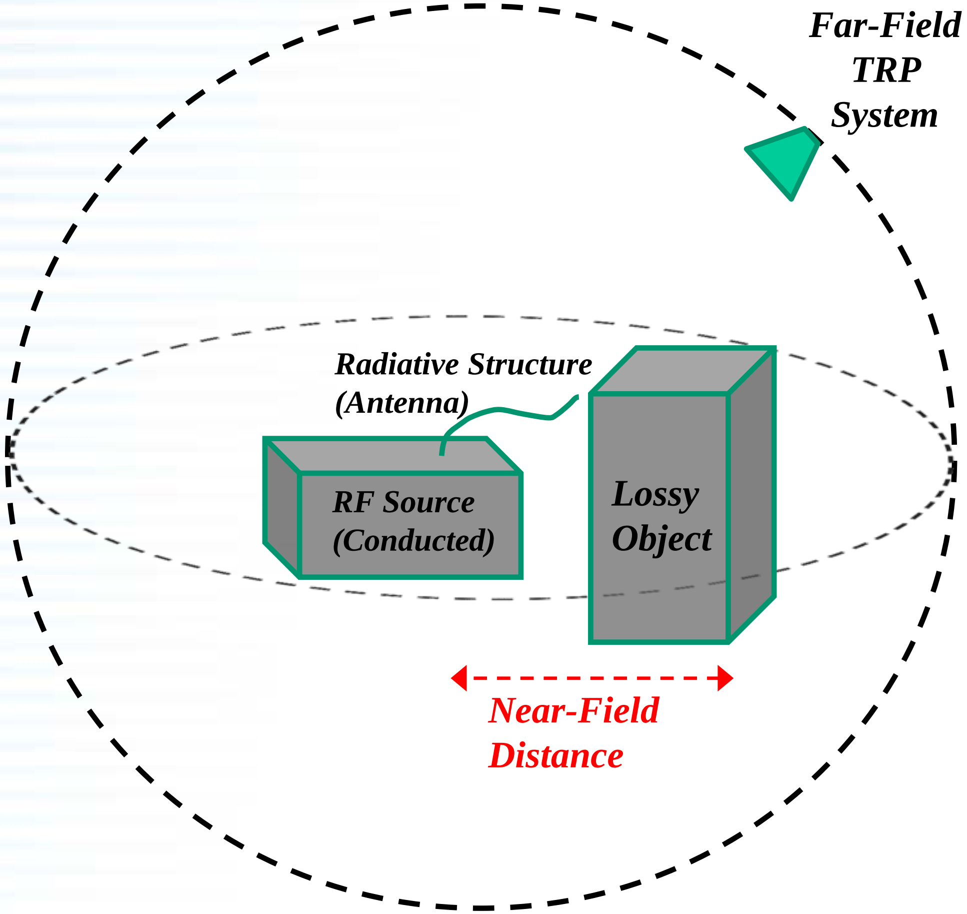


Deep Dive 1
URS Coupled in the Near-Field

- **Analysis**: exploring cases where an RF device coupling in the near-field with a lossy conducting object leads to an increase of total radiated power
- **Conclusion**: the presence of a near-field coupled object may increase the URS radiated power but to a level still well within the 1-*mW* RF Exposure test exemption threshold

URS Coupled in the Near-Field (II)

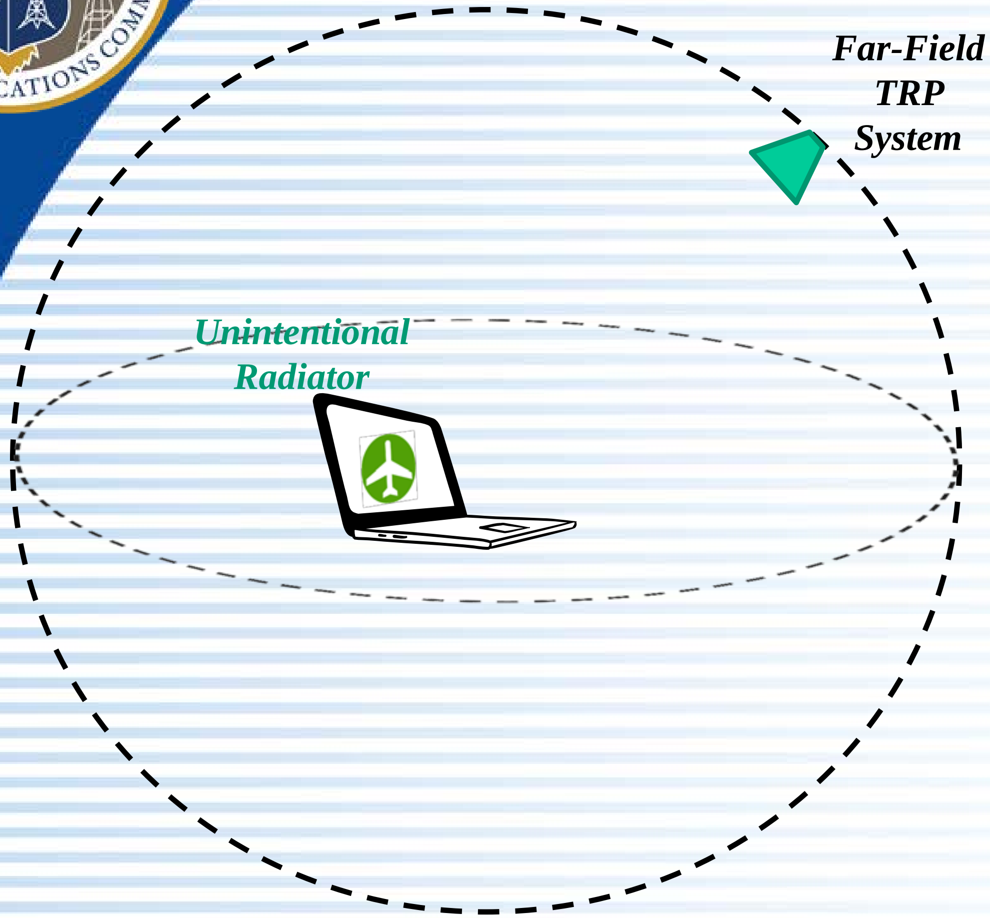




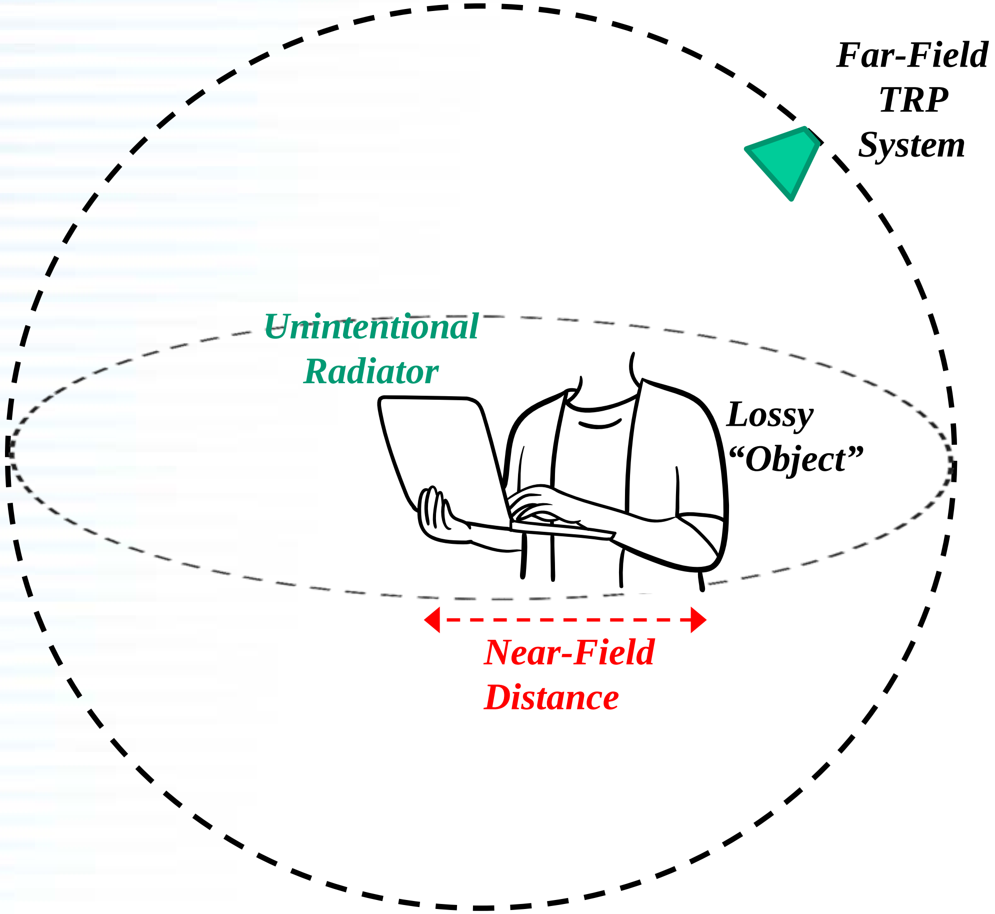
a) Reference case: unobstructed (free space) radiator emitting in the far-field

b) The same radiator in a) is now coupled in the near-field with a lossy object

URS Coupled in the Near-Field (II)

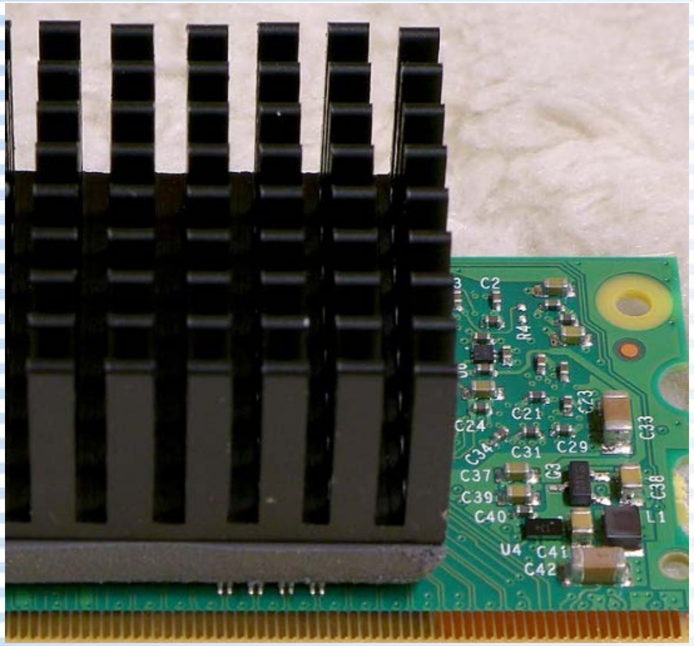


Example - Laptop in airplane mode: digital device, unintentional radiator, emissions measured in the far field

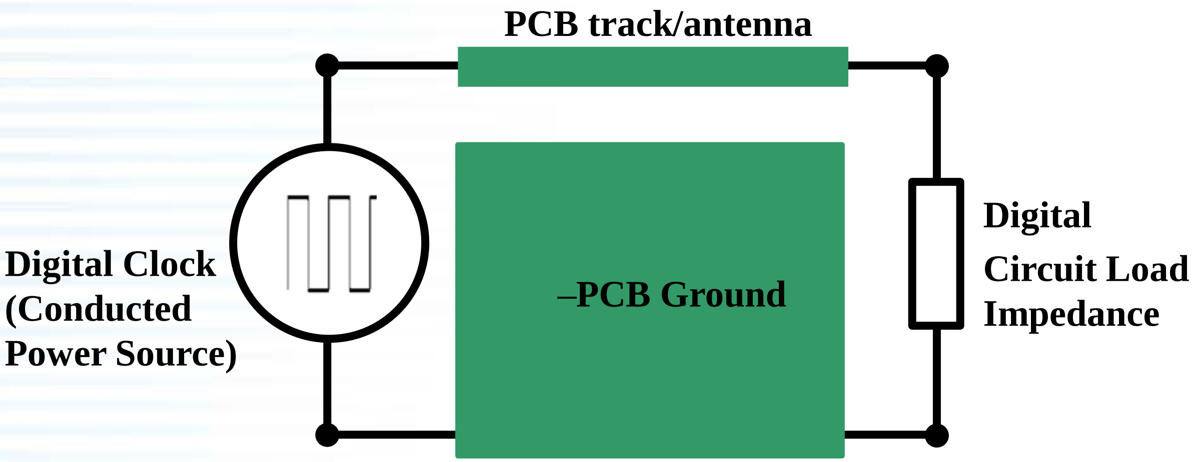


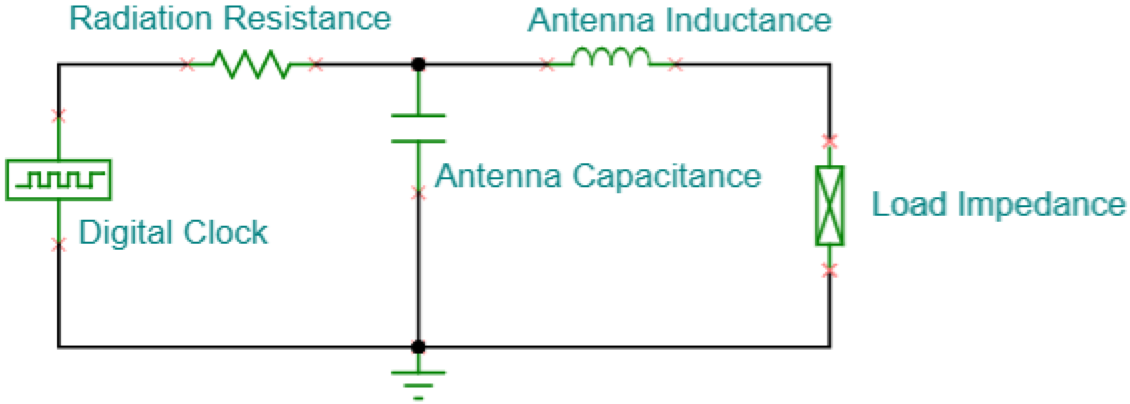
The URS is coupled in the near-field with the human body, a lossy conductor

URS Equivalent Circuit Model (I)



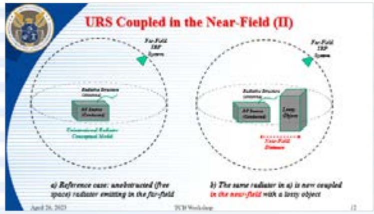
PCB tracks and heat sinks in a digital electronics board

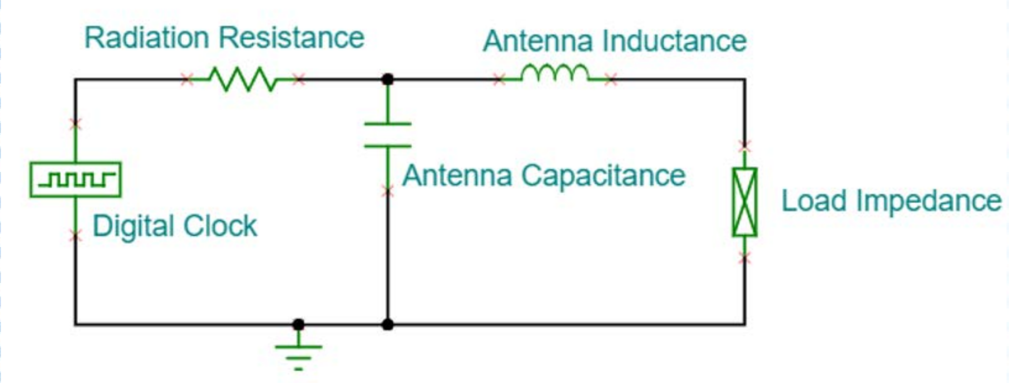




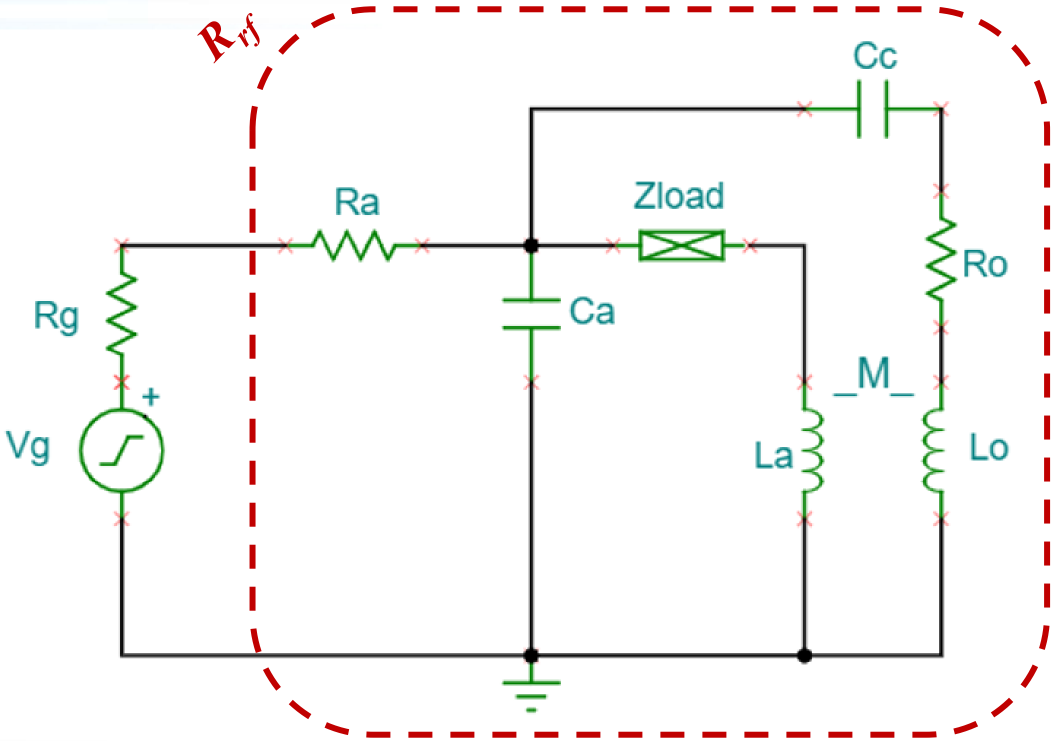
Conceptual Circuit Model

Coupling Circuit Model (II)





Stand-alone URS Circuit Model (Digital Logic example)



URS Circuit Model that includes both capacitive and inductive coupling in the near field to an object (lossy conductor) characterized by a resistance Ro and inductance Lo)

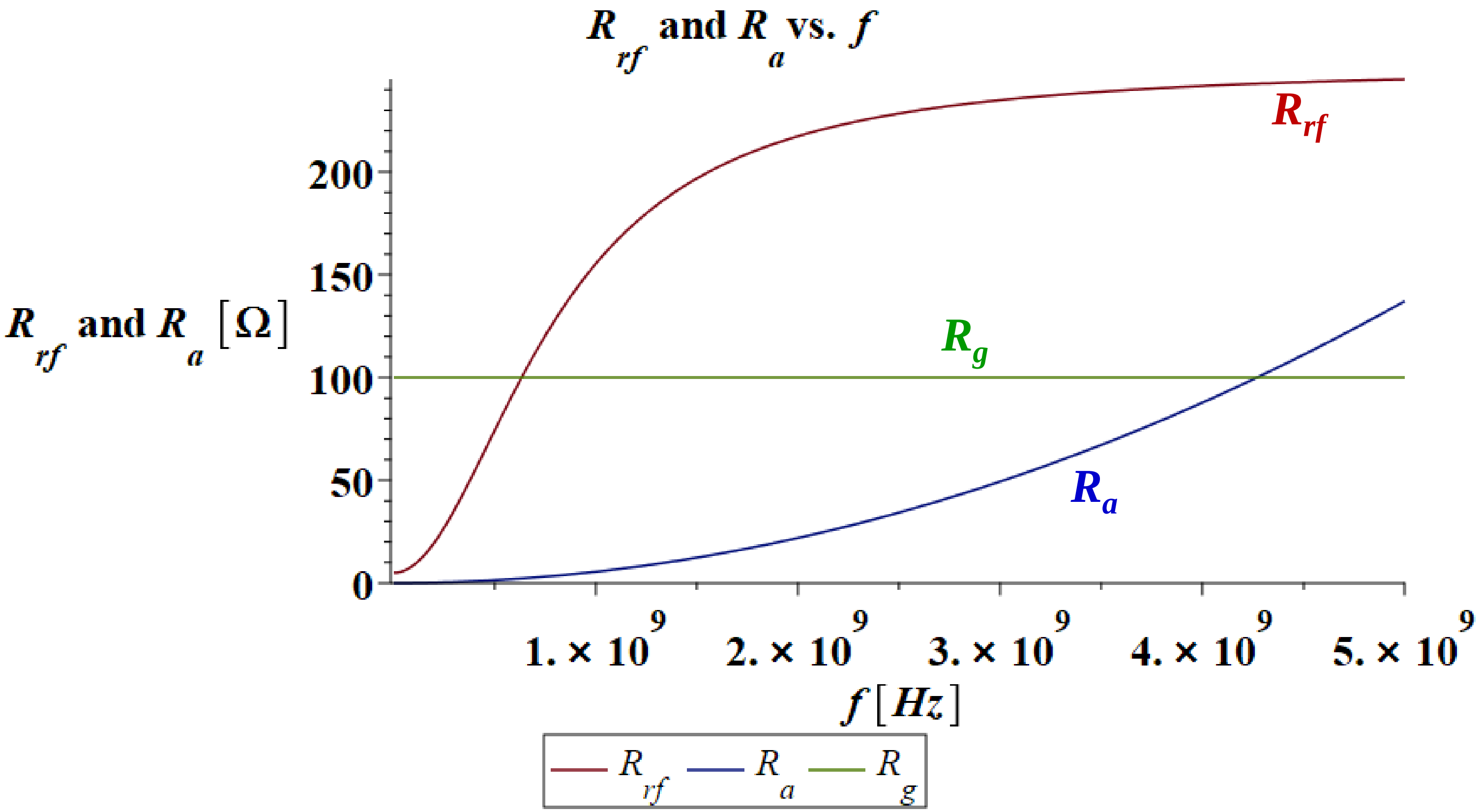
Coupling Circuit Model (II)

Digital Circuit Example URS modeling - Equivalent resistance vs. frequency shows changes in matching impedance with URS conducted source

R_{rf} = Equivalent resistance of the URS with the near field coupled load

R_a = Antenna resistance of the URS without near-field coupled object (dipole model)

R_g = Resistance of the URS generator, the conducted power source



Both R_{rf} and R_a=R_{dipole} change vs. frequency: only at f>4 GHz the dipole resistance approaches impedance matching conditions with the R_g=100 W of the URS conducted power circuitry

URS Modeling Parameters

Examples of URS Reference Scenarios

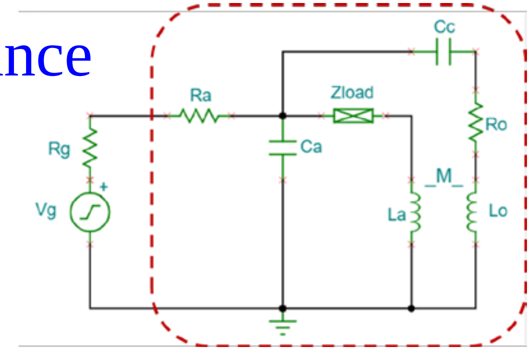
	Digital Circuit	Power Supply for WPT	High-Power Inverter
RF Voltage (V)	5	220	500
RF Current (A)	0.05	10	100
Generator Resistance (Ω)	100	22	5
Frequency (Hz)	10^9	10^5	$3 \cdot 10^5$
Conductor Length (m)	0.05	0.5	1.
Conductor Radius (m)	$0.5 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$10 \cdot 10^{-3}$

Modeling scenarios: estimated characteristics of some RF unintentional radiators sources

Modeling Results

URS Equivalent Circuit Modeling Analyis

- The URS radiating structure may be modified in the presence of near-field coupling with another conductor.
- This modified radiating structure may provide a better impedance matching with the impedance of the URS conducted power circuitry.



- In these conditions the URS radiated emissions may increase with respect to the case of unobstructed emissions (no coupled additional conductor) as in 15-B tests
- For Part 15 B-compliant URS, an extended-range parameter exploration indicates that the increased power due to near-field coupling is still orders of magnitude smaller than the 1 *mW* threshold below which the RFX test exemption applies.

Deep Dive 2
URS Power Estimates from Near-Field Data

- **Analysis** - Part 15-B test data collected in the near-field, may lead to a power estimate that is less than the actual power radiated by the device.
- **Conclusions**
  - For Part 15-B compliant URS, in most cases, the radiated power estimate based on near-field components does not reach the 1-*mW* RFX test exemption level
  - Exceptions may be found for magnetic-type sources emissions in the tens of kHz

Example

- 15B-compliant magnetic coil, powered at 9 kHz coil
- From §15.109: r_{15B} = 300 m, E_{15B} = 266 μV/m
- r_{15B} / r_{nf} = 300 m/ 5305 m ≈ 0.06 => very near field
- Computing Z_w via linear approximation: $Z_w \approx 21\ \Omega << 377\ \Omega$
- Power estimate via far-field formula below 1-*mW* threshold

$$P_{ff} = 2 \cdot \pi \cdot r_{15B}^{\ 2} \frac{E_{15B}^{\ 2}}{Z_0} \approx 0.21\ mW$$

- Power estimate via general formula above 1-*mW* threshold

$$P = 2 \cdot \pi \cdot r_{15B}^{\ 2} \frac{E_{15B}^{\ 2}}{Z_0} \left(1 + \frac{Z_0^{\ 2}}{Z_w^{\ 2}} \right) \approx 33\ mW$$

Radiated Power Estimate

- If Z_0 is the free-space wave impedance, and E and H the magnitude of the electric and magnetic fields at a radial distance r from the source, the RF radiated power density (W/m^2, rate of energy transport per unit area) is

$$\frac{P}{4\cdot\pi\cdot r^2} = \frac{1}{2}\left(\frac{E^2}{Z_0} + Z_0 H^2\right)$$

- It then follows that the total radiated power is

$$P = 2\cdot\pi\cdot r^2\left(\frac{E^2}{Z_0} + Z_0 H^2\right)$$

- In the far-field $Z_0 = E/H$ and the previous expression can be written as

$$P = 2\cdot\pi\cdot r^2\left(\frac{E^2}{Z_0} + Z_0 H^2\right) = 4\cdot\pi\cdot r^2\frac{E^2}{Z_0}$$

Power from E and H in the Near-Field

Case of Part 15B electric field measurements not in the far field (for practical reasons, *e.g.*, due to size of the measurement setup and/or low S/N).

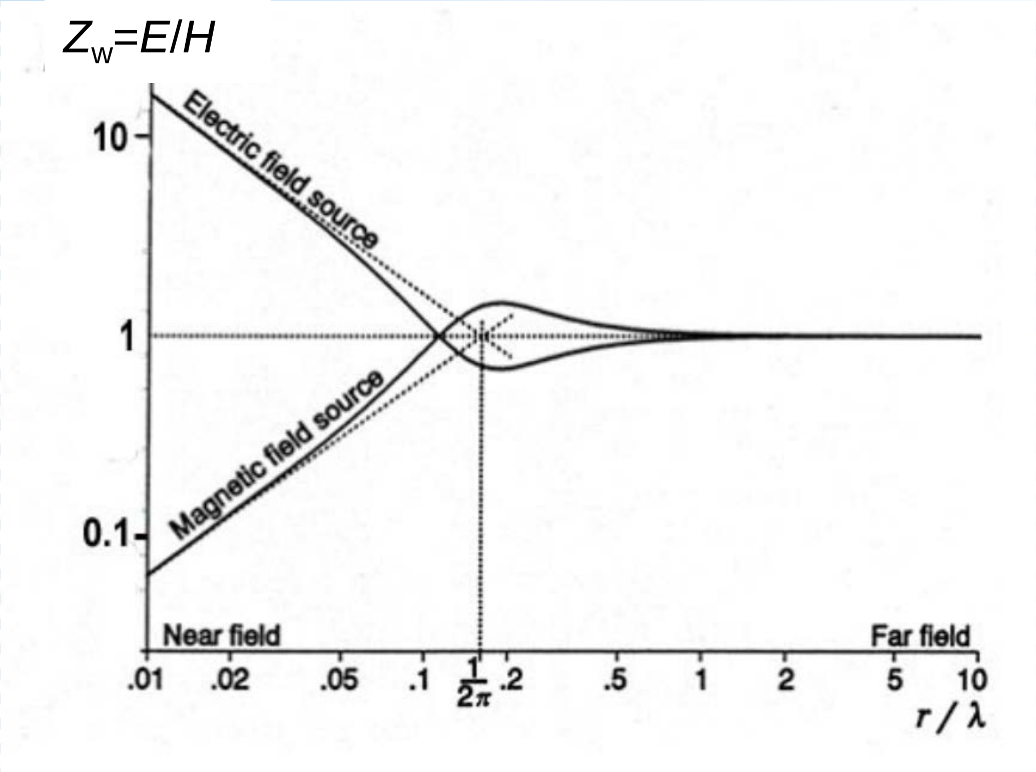
- In general, then $Z_w = E/H \neq Z_0$ and by replacing $H = E/Z_w$ it is found

$$P = 4 \cdot \pi \cdot r^2 \frac{1}{2}\left(\frac{E^2}{Z_0} + Z_0 H^2\right) = 4 \cdot \pi \cdot r^2 \frac{E^2}{Z_0} \frac{1}{2}\left(1 + \frac{Z_0^{\,2}}{Z_w^{\,2}}\right)$$

- When $Z_w << Z_0$ then $Z_0/Z_w >> 1$ and the radiated power is larger than for the far-field estimate $P = 4\,\pi\, r^2\, E^2/Z_0^{\,2}$
- In these conditions (i.e. $Z_w << Z_0$), using only the electric field value measured in the near field may lead to an underestimation of the total radiated power, because $E/H = Z_0$ does not hold.

Wave Impedance in the Near-Field

- The case $Z_w << Z0$ corresponds to a "magnetic source" in the near field, as it can be seen, for instance, comparing the field solutions for small dipoles:



Reference [K. McDonald, 2004]

URS with Small Wave Impedance (I)

- In order to identify situations of interest where $Z_w << Z_0$, it is sufficient to find the RF frequency required to make the Part 15 B testing distance r_{15B} well below the near-field boundary $r_{nf} < \lambda/(2\pi)$.
- If $r_{15B} = \lambda/(2\pi) = c/(2\pi f) \Rightarrow f = c/(2\pi r_{15B})$. For instance, for $r_{15B} = 30\ m$ it is found $f = 1.6\ MHz$.
- For the case of interest where $Z_w << Z_0$, r_{15B} needs to be well within the near field: this can be seen in the previous Z_w plot, where Z_w for a small dipole decreases about a factor of ten for $r \approx r_{nf}/10$.
- The exact determination of the wave impedance Z_w requires a near-field solution for a specific antenna configuration, in this case, a finite-size loop antenna may provide a realistic model for a practical source of interest.

URS with Small Wave Impedance (II)

- However, an estimate for identifying realistic scenarios of interest may be performed without the need for a solution for the near-field.
- Goal: establish if, due to the larger Z_w , the power estimate is increasing enough as compared to the far-field estimate, i.e., if

$$2 \cdot \pi \cdot r^2 \frac{E^2}{Z_0} \left(1 + \frac{Z_0^{\,2}}{Z_w^{\,2}} \right) \gg 4 \cdot \pi \cdot r^2 \frac{E^2}{Z_0}$$

- The focus is on the conditions where the power estimate can reach and exceed the 1-*mW* threshold above which RF exposure testing is required
- Thus one can impose

$$P = 2 \cdot \pi \cdot r_{15B}^{\,2} \frac{E_{15B}^{\,2}}{Z_0} \left(1 + \frac{Z_0^{\,2}}{Z_w^{\,2}} \right) = 10^{-3}$$

and then solve for Z_w.

URS with Small Wave Impedance (III)

- Data for r_{15B} and E_{15B} are available from §15.109 (and 15.209:

Frequency of emission (MHz)	Field strength (microvolts/meter)
30–88	100
88–216	150
216–960	200
Above 960	500

Frequency (MHz)	Field strength (microvolts/meter)	Measurement distance (meters)
0.009–0.490	2400/F(kHz)	300
0.490–1.705	24000/F(kHz)	30
1.705–30.0	30	30
30–88	100 **	3
88–216	150 **	3
216–960	200 **	3
Above 960	500	3

URS with Small Wave Impedance (IV)

- For instance, solving for Z_w, the following cases are identified:

Z_w / Z_0	f	$r_{nf} = \lambda/(2\pi)$	r_{15B}	r_{15B}/r_{nf}	r_{15B} in the Near-Field?
0.345	9 kHz	5300 m	300 m	0.056	Y
0.187	16 kHz	2984 m	300 m	0.1	Y
0.0184	160 kHz	298.4 m	300 m	1.006	N

- These data indicate that URS power is underestimated based on a Part 15B field calculation only for very low-frequency coils, well below 100 kHz.
- In these cases, 15B-compliant URS devices may have a radiated power above 1-*mW*

Forthcoming RF Exposure Policies

- Tolerances
- Mobile vs. Portable
- Host Certification with Customized *Modules*
- RF eXposure for *Module* Integration
- Extension of SPLSR Formula
- 447498 “Satellite” Publications
- Time-averaging in RFX Evaluations (II)

Revising "Tune-up tolerance" Policy

Policy in Consideration for the Forthcoming 447498v07

- No distinction shall be made between "tune-up tolerance" and any other tolerance (production, calibration, or test equipment).
- The "reported SAR" (or MPE) shall be defined in reference to the device's overall specification tolerance, as declared by the manufacturer.
- If a product is fabricated under low accuracy standards, then the manufacturer is implicitly penalized because the product needs to be tested to comply with the applicable limit minus the tolerance.
- Example: ±10% tolerance on power will require using lower a max 1-g SAR:

$$SAR_{max} = 1.6 - 0.16 = 1.44 \text{ W/Kg}$$

Assessing Portable vs. Mobile Categories

Cases for *not-well-defined* portable or mobile conditions

- New KDB Inquiry categories soon to be made available (w/formal announcement)
- KDB to be filed: 1st category "Equipment Compliance Review", 2nd "Category "Mobile vs. Portable"
- Case description shall include use-case conditions defined in an objective, defendable manner.
- FCC may require to use of grant comments for *not-well-defined* portable or mobile conditions: this includes situations where there is a non-standard minimum approach distance (e.g. mobile device compliant distances for more than 20 cm)
- FCC may require that user's manual must report the same language as the grant comment

Host Certification with Customized *Modules*

Clarification on the Use of Modular Grant Certifications

- Not a new policy: “host certification” done by the module grantee while using a *customized module* as an alternative to Permissive Changes
- This approach is a viable alternative to C2PC for technologies that require complex analyses in order to establish compliance with module integration

RF eXposure for *Module* Integration

Policy in Consideration for the Forthcoming 447498v07

- In principle, devices with modular grant certification ("*Modules*") may be integrated into all devices
- In a "crowded environment" (*e.g.*, a cell phone handset) the *Module* RF emissions patterns may be re-shaped by nearby materials
- Specific integration policy to be set in place in order to avoid field perturbations that may increase RF exposure contributions of the module w.r.t. grant levels
- By policy, host integration constraints will be implicitly considered with specific provisions for simultaneous transmissions (e.g. KDB 447498-SPLSR formula)
- Revised SPLSR application policy to consider modules placed at different heights from the ground plane

Extension of SPLSR Formula

KDB 447498-v07 New Provisions and Clarifications

- Expanding from the Oct 2022 workshop general outline
- “Generalized” SPLSR formula updates to include power density contributions and contributions of MPE below 4 MHz in place of SAR (the latter already allowed for non-SPLSR evaluations per Oct 2022 Workshop policy)
- For some special cases, considering a spot check policy to confirm the applicability of the SPLSR test
- Considering allowance of validated numerical simulations, when allowed for certification of the standalone device)

447498 “Satellite” Publications

New Provisions and Clarifications

- Satellite (nothing to do with the ones in space) publications of 447498: update in progress for consistency
- List of KDB Publications currently under revision to sync with 447498-v07
  - KDB 616217 “SAR evaluation considerations for laptop, notebook, netbook and tablet computers”
  - KDB 648474 “SAR evaluation for handsets, wireless charging battery covers”
  - KDB 996639 “Modules”

Time-averaging in RFX Evaluations (I)

Clarification on Equipment Authorization Policy

- To evaluate the environmental impact of RF on humans, 47 CFR 1.1310(e)(1) provides limits on SAR and Maximum Permissible Exposure (MPE), specified for an averaging time of 30 min., and 6 min., for general public and occupational exposure, respectively
- Per OET equipment authorization policy, the uniform criterion for all RF devices to obtain a grant of certification, requires demonstrating compliance to limit stated in KDB 447498, and using the time averaging window specified as follows:

Frequency (GHz):	< 3	3–6	6–10	10-16	16-24	24-42	42-95
Max. Averaging Time (s):	100	60	30	14	8	4	2
From: Oct. 2018 TCBC Workshop, "RF Exposure Order/NPRM Issues"							

Time-averaging in RFX Evaluations (II)

- 2.1093(d)(4) allows "source-based" exposure time averaging to determine compliance with general population/uncontrolled SAR limits
  - "Source-based" means inherent transmission property or duty factor of a device, such typically $\ll$ 30 min. (*e.g.*, TDMA frame-time)
  - Other averaging times generally not applicable
- Other considerations related to duty factor devices are discussed in KDB 388624-D02, "DUTFCT" PAG Item.
- Time-averaging alternatives are under review in rulemaking docket no. 19-226

Questions?